The *Necturus lewisi* Study: Introduction, Selected Literature Review, and Comments on the Hydrologic Units and Their Faunas

JOHN E. COOPER AND RAY E. ASHTON, JR. [1]

North Carolina State Museum of Natural History, P. O. Box 27647, Raleigh, North Carolina 27611

ABSTRACT.— Of the three species of *Necturus* occurring in North Carolina, only *N. lewisi*, the Neuse River Waterdog, is endemic to the state. Described as a subspecies of *N. maculosus* by C. S. Brimley in 1924, the salamander occurs in the Neuse and Tar rivers and their tributaries, from the eastern Piedmont Plateau nearly to tidewater in the Coastal Plain. Because of its endemicity and limited known distribution, *N. lewisi* became a candidate for pre-listing studies by the Office of Endangered Species, U.S. Fish and Wildlife Service, and the N.C. Wildlife Resources Commission. In 1977, using radioisotope tagging (^{60}Co), the N.C. State Museum conducted a preliminary behavioral study of *N. lewisi*, and in 1978 began a 3-year contractual study of the animal's distribution, ecology, and ethology. Most prior studies were taxonomic, but some provided information on various aspects of life history, habitat preference, and preliminary conservation status. The Neuse and Tar-Pamlico hydrologic units support similar faunas, and contain other endemic species, some of which are considered by biologists to be at risk.

INTRODUCTION

Three species of *Necturus* occur in North Carolina: *Necturus maculosus maculosus* (Rafinesque), the Mudpuppy, inhabits several streams in the Tennessee River basin of the mountains and has a broad distribution that ranges from southeastern Canada west to Kansas and south to northern Alabama; *Necturus punctatus punctatus* (Gibbes), the Dwarf Waterdog, occurs in streams and rivers of the Coastal Plain and the eastern edge of the Piedmont Plateau, ranging along the Atlantic seaboard from southeastern Virginia to central Georgia; and *Necturus lewisi* (Brimley), the Neuse River Waterdog, which is endemic to the Neuse and Tar-Pamlico river basins in both the eastern Piedmont Plateau and the Coastal Plain, occurring nearly to tidewater. The two eastern species, *N. punctatus* and *N. lewisi*, are sympatric and possibly syntopic in the Fall Line Zone and parts of the upper Coastal Plain.

[1] Present address: International Expeditions, Inc., 1776 Independence Court, Birmingham, Alabama 35216

Although six decades have passed since C. S. Brimley (1924) described *N. lewisi* (as a subspecies of *N. maculosus*), little information on this large aquatic salamander has been published. Several of the few papers that included discussions of the taxonomy, distribution, and ecology of the animal contained incomplete or incorrect information. This can probably be attributed to the relatively small number of specimens, from very few localities, that were available in collections until around 1970.

Viosca (1937) elevated *N. lewisi* to full species status, and Brimley (1944) seems to have been the first to recognize that the salamander was restricted to the Neuse and Tar drainages. Since both rivers rise and debouch in North Carolina (see Figs. 1 and 2 in Braswell and Ashton, this issue), *N. lewisi* is endemic to the state. Because its endemicity and limited known distribution could make it vulnerable to pollution and habitat modification, and because its "population size and trends are unknown," Stephan (1977:317-318) advised that *N. lewisi* be designated a species of Special Concern. The dearth of information on its distribution and biology made *N. lewisi* a candidate for review as part of the endangered species program in North Carolina. In 1977, the North Carolina Wildlife Resources Commission provided the North Carolina State Museum with funds from its Carolina Conservationist Program for a preliminary behavioral study of the species. Among other accomplishments, the study established that radioisotope tagging (^{60} Co) of *N. lewisi* was a reliable method for monitoring the salamander in its natural habitat (see Ashton, this issue). In 1978, the Wildlife Resources Commission, through a cooperative agreement with the Office of Endangered Species, U.S. Fish and Wildlife Service (under Title 6 of the Endangered Species Act of 1973), funded a 3-year contract study of *N. lewisi* by the museum. Ray E. Ashton, Jr., formulated the contract proposal and served as director of the project, and Alvin L. Braswell coordinated the extensive field studies. Field technicians were Angelo Capparella, Keith Everett, Ernie Flowers, Paul Freed, Roger Mays, Eric Rawls, and Jerry Reynolds.

The main goals of the *N. lewisi* project were to gather information on the distribution, ecology, and behavior of the species, but the study yielded results that exceeded these objectives. Data were also collected on other aspects of the animal's biology; some of these results are reported elsewhere in this issue. Other data were collected on *N. punctatus*, which occurs with *N. lewisi* at many localities but has a broader distribution. These results will be reported at another time. The general collections made in both the Neuse and Tar rivers were planned to include other amphibians, reptiles, fishes, and many kinds of benthic invertebrates (particularly crayfishes; Cooper and Cooper, in ms.), without compromising the project's primary objectives. As a result of

this broader emphasis we learned not only a great deal about *N. lewisi* and its habitat, but also about its associates. Comments concerning some of these associates are provided later in this paper.

REVIEW OF SOME PREVIOUS STUDIES

Much of the earlier information on *N. lewisi* resides in unpublished sources such as the theses of Hecht (1953) and Fedak (1971), or is dispersed in published and unpublished sources that are not readily available. The following is a brief chronological review (with annotation as appropriate) of some of the more pertinent literature and unpublished manuscripts that have appeared since *N. lewisi* was described. See Braswell and Ashton (this issue) for review of the literature that deals specifically with distribution and habitat.

C. S. Brimley (1924) described *Necturus maculosus* from the Neuse River near Raleigh, basing his description largely on specimens collected in the Raleigh area since 1894. Nearly all of Brimley's specimens were caught on hook and line by fishermen. A number of specimens, including the holotype (USNM 73848), were brought to Brimley by Frank B. Lewis, hence the patronym. Brimley noted that *N. m. lewisi* was smaller than *N. m. maculosus*, and had spotted as opposed to striped juveniles (less than 3.5 inches long).

Bishop (1926) and Cahn and Shumway (1926) described the adults and postlarvae or juveniles of *N. m. lewisi*, but the descriptions of the larvae left a great deal to be desired. In his tentative revision of the genus *Necturus*, Viosca (1937) elevated *lewisi* to species rank, saying (p. 120) "a study of North Carolina specimens has convinced me that Brimley's form *lewisi*, described as a subspecies of *maculosus*, merits full specific rank...." This decision was largely based on the ventral spotting pattern, which differed from that of both *N. maculosus* and *N. beyeri* in size, number, and color of spots, and on comparative numbers of teeth. Viosca examined 11 juveniles and 4 larvae, described the larval pattern and coloration, and mentioned that, among other features, the dorsum lacked spots. He further noted that both dorsal and ventral spotting increase with age, and are well defined at a length of 90 mm, but failed to indicate whether this was snout-vent length (SVL) or total length (TL). Viosca (1937) erroneously gave Brimley's field number (CSB 6868) as the USNM catalogue number of the holotype (USNM 73848).

Brimley (1939) considered *N. lewisi* a full species, but Bishop (1941) retained the trinomial combination. Later, however, Bishop (1943) accepted species rank for *N. lewisi*, provided the first photograph of an adult (a female from Little River, Neuse River basin), and gave a detailed account of pattern, dentition, and coloration. He also described a male with swollen cloaca, collected by Lewis on 24 March 1920, and an egg-laden female that Lewis collected on 8 April 1919. These speci-

mens led Bishop (1947:34) to suggest "an early-spring mating season for this species, although some males of *maculosus*, which has a fall mating season, are known to retain the swollen glands until spring."

Although Schmidt (1953) retained the trinomial, Hecht (1953) accepted Viosca's (1937) taxonomic change and placed *N. lewisi* and *N. beyeri* in a *Necturus lewisi* superspecies group. Both species differed from their congeners in having non-striped larvae and spotted medium-sized adults. The *N. lewisi* superspecies was considered intermediate between the species *N. maculosus* and *N. punctatus*. Hecht's series contained only 20 adult *N. lewisi*, so he could not address ontogenetic changes in dentition, body proportions, and other features. He did note a maximum SVL of at least 175 mm, a minimum breeding size between 100 and 105 mm SVL, and a change to adult pattern at 130 mm SVL. Hecht (1958) opined that the species of *Necturus* appeared to be cold-adapted salamanders, active only in the colder seasons and inactive during hottest months. He further speculated that maximum and minimum breeding size may be an adaptation to thermal regimes of the habitat, concluding (p. 115): "natural selection has resulted in the adaptation of the southern species to higher temperatures and a higher metabolism by reduction of the minimum breeding and maximum size of the species." He considered the *lewisi* group the most primitive in the genus, with *N. punctatus* an early derivative of the proto-*lewisi* ancestor, and *N. maculosus* a direct and recent (advanced) descendent of the *lewisi* group. He stated that the striped larva of *N. maculosus* is more specialized than the primitive unstriped larval type of the *lewisi* and *punctatus* groups. (See Ashton and Braswell, 1979, for discussion of the striped post-hatchling larva of *N. lewisi*; also see Sessions and Wiley, this issue, for chromosome evolution in *Necturus*.)

Blair et al. (1968) included *lewisi* as a full species. Neill (1963:173), defending species status for *N. alabamensis* Viosca, said that *N. lewisi* "most resembles, and is probably most nearly allied to, *N. beyeri* (*sensu* Viosca) even though the two inhabit well-separated portions of the Coastal Plain. A distribution of this kind, in a group as ancient and conservative as the waterdogs, suggests that *lewisi* and *beyeri* had a common ancestor in the lowlands that bordered the shoreline of the old Cretaceous Embayment. As the shoreline retreated southward, exposing what is now the Coastal Plain, the range of the *lewisi-beyeri* animal was fragmented." Brode (1970) revised the genus *Necturus*, using osteological criteria to relegate *N. lewisi* to subspecies status under *N. maculosus*, but this arrangement was not very widely employed.

Fedak (1971), in the most thorough life history study of North Carolina *Necturus* to that time, provided information on more than 600 *Necturus* (*punctatus* and *lewisi*) from 32 North Carolina localities, all collected from the fall of 1966 through the summer of 1969. Of these,

230 were from the Neuse and Tar drainages. Fedak's study showed that sexual maturity in male *N. lewisi* occurred at 102 mm SVL, and the first yolked oocytes and thickened and coiled oviducts were found in females at 100 mm SVL. Age at sexual maturity was given as 5.5 to 6.5 years. Male testes were swollen in early fall, and the dark, involuted vasa deferentia were packed with sperm from November through May. The cloacal glands were swollen during this period, but swelling progressively decreased from late March through May. Sperm were present in female spermathecae from December through May, the same period in which the male cloacal glands were most swollen and the vasa deferentia loaded with sperm. The largest yolked eggs were found in April and May, and the smallest in May and July. From these findings Fedak concluded that *N. lewisi* (and, from other data, *N. punctatus*) mate in winter, and that egg deposition probably occurs in May or early June.

Fedak (1971:97) also commented on relationships, expressing the opinion that "*Necturus lewisi* is probably most closely related to upland populations of *N. maculosus* in the Tennessee River." He further hypothesized that *N. lewisi*, *N. maculosus*, and *N. alabamensis* were closely related, and that *N. punctatus* was most similar to *N. beyeri* Viosca.

Stephan (1977) provided a general description of *N. lewisi*, summarized what was known of its distribution and natural history, then suggested a conservation status of Special Concern. He also noted (p. 318) that, "The Neuse River Waterdog was considered a species of *Special Concern* at the Workshop on Threatened and Endangered Vertebrates of the Southeast."

Ashton and Braswell (1979), as part of the preliminary phase of the overall project, found and described the first reported nest and hatchling larvae of *N. lewisi*. The nest, discovered on 2 July 1978, was under a flat rock in 1.2 m of water in the middle of the Little River, northeastern Wake County, about 2 m from shore. Thiry-two empty egg capsules, and three with larvae that soon emerged, were attached to the underside of the rock. An adult male (147.6 mm SVL) tagged with ^{60}cobalt wire was in attendance in a depression in the sand-gravel substrate directly beneath the eggs. Four other larvae were dip-netted within 5 m of the nest site. These authors reported that, although hatchlings of both *N. lewisi* and *N. maculosus* are uniform in color and nearly indistinguishable, the post-hatchling larvae of *N. lewisi* have stripes when between 21 and 41 mm SVL. This striped pattern begins to fade into the pattern described by Viosca (1937) for specimens of "3½ inches" (ca. 90 mm). This was the size considered by Brimley to be larvae, but we now know that individuals of this size are subadults. The striped pattern of post-hatchling *N. lewisi* is quite distinct from that of post-hatchlings of all other species of *Necturus*. Ashton and Braswell (1979:18-19) provided the first illustrations of *N. lewisi* hatchlings and

older larvae, drawn by Renaldo G. Kuhler, scientific illustrator at the state museum.

Ashton et al. (1980) reported electrophoretic analyses of 17 loci coding for enzymes in 20 *N. lewisi*, 8 unspotted *N. punctatus* from the Neuse River drainage, 8 spotted *N. punctatus* from the Lumber-Pee Dee drainage, and 21 *N. maculosus* (1 from North Carolina). They concluded (p. 46): "the specific status of *N. lewisi* is confirmed by electrophoretic data as well as by the distinct larvae described by Ashton and Braswell (1979). Further, *N. punctatus* appears to have been reproductively isolated from sympatric *N. lewisi* and from allopatric *N. maculosus* for a considerable period of time, and spotted *N. punctatus* from the Pee Dee drainage (North and South Carolina) appear on the basis of electrophoresis to be genetically similar to the unspotted populations of the Neuse River system."

Color photographs of adult *N. lewisi* were provided by Behler and King (1979) and Martof et al. (1980).

THE HYDROLOGIC UNITS

Both the Neuse and Tar river systems head in the eastern Piedmont Plateau of the state, drain generally southeast through the Coastal Plain, then debouch at broad, fairly deep, saline estuaries that feed into Pamlico Sound. Approximately one-third of each river basin lies in the Piedmont Plateau and Fall Line Zone (which is some 30 to 40 miles wide), and two-thirds of each basin is within the Coastal Plain. Not unexpectedly, the characteristics of the upper hydrologic units differ considerably from those of the lower basins. The Piedmont Plateau tributaries flow through valleys of various depths between rolling hills. In the main, their banks are somewhat precipitous, their floodplains comparatively narrow, and their waters graphically lotic, with a combination of pools and rocky or gravelly rapids and riffles. Substrates are sand-gravel or sand-silt. Bayless and Smith (1962) recorded average Piedmont stream gradients of from 14 to 19 feet per mile for the Eno, Flat, and Little rivers, all of them Neuse feeders, and 2 feet per mile for the mainstem Neuse. The average Piedmont gradient for the Tar was reported as 2.8 feet per mile (Smith and Bayless 1964).

By contrast, the Coastal Plain tributaries of both rivers flow through flatter terrain and have broader floodplains. Their slow-moving waters have a low average gradient (0.6 feet per mile for the Neuse; Bayless and Smith 1962). The larger Coastal Plain tributaries often have high banks and bluffs on their south side, and broad flats and swamps on their north side (Stuckey 1965). The substrates of these streams are muck, sand, and detritus. The Coastal Plain streams and rivers are underlain with relatively soft sedimentary bedrock of from Cretaceous to Recent age. In the Fall Line Zone this gives way to a bedrock con-

glomerate of metamorphic and igneous rocks of unequal hardness and resistance to erosive degradation. Within the Piedmont the bedrock is diversified, primarily granite and other crystalline rocks. North of Raleigh the Neuse River flows northeast for a few miles in softer sedimentary rocks of Triassic age.

Neuse River

The westernmost headwaters of the Neuse River are tributaries of the Eno and Flat rivers, and Deep Creek, in the Piedmont Plateau of southern Person and northeastern Orange counties. Deep Creek confluences with the South Flat River in northern Durham County to form the Flat River, and the Flat and Eno rivers confluence at the Durham-Granville county line northeast of Durham to form the main trunk of the Neuse. Little River, long known as a *lewisi* site, is a major eastern tributary that rises in southwestern Franklin County and confluences with the mainstem Neuse in central Wayne County, southwest of Goldsboro. Two large western tributaries — Swift and Middle creeks —head in southern Wake County and join the Neuse in the Coastal Plain of central Johnston County, just west of Smithfield. An extensive Coastal Plain tributary — Contentnea Creek — draining over 980 square miles and with many lower-order tributaries, confluences with the Neuse River at the junction of Pitt, Lenoir, and Craven counties northeast of Kinston. Paralleling Contentnea Creek to the east is a second Swift Creek, which rises in Pitt County and confluences with the Neuse in Craven County, northwest of New Bern. Another large Coastal Plain subsystem, draining about 515 square miles, is the Trent River. It heads in southern Lenoir and western Jones counties, and empties into the Neuse River Estuary at New Bern. (See Braswell and Ashton, this issue, for additional comments on the Trent River). All told, the Neuse River system drains a watershed of around 6,200 square miles. Among North Carolina rivers the Neuse River basin is third in area drained, exceeded only by the Cape Fear (ca. 9,200 sq. mi.) and Yadkin (ca. 7,200 sq. mi.) river basins.

Tar-Pamlico River

The Tar River has its westernmost headwaters in the Piedmont Plateau of eastern Person, southern Granville, and southern Vance counties. Its northeastern headwaters are small streams in southern Warren and Halifax counties. Fishing Creek and its tributaries, which drain an area of about 760 square miles, comprise a major subdrainage to the north and east of the mainstem Tar River. Fishing Creek confluences with the main trunk of the Tar in the Coastal Plain of central Edgecombe County, north of Tarboro. South of the Fishing Creek subdrainage is an area of some 350 square miles drained by Sandy and Swift

creeks; these streams join the Tar River in Edgecombe County, a few miles west of the Fishing Creek confluence. The largest Coastal Plain tributary is Tranters Creek, a slow-moving blackwater stream that rises in southwestern Martin County, flows south, and confluences with the Tar northwest of Washington, Beaufort County. East of Washington the Tar River becomes the Pamlico River, which flows southeast into the Pamlico River Estuary and then enters Pamlico Sound. The Tar-Pamlico River system drains a watershed of around 3,100 square miles.

COMMENTS ON THE FAUNAS

Throughout their lengths the Neuse and Tar rivers are parallel systems, and seem to support nearly identical faunas. Bailey (1977:275) remarked that the Tar must have been a tributary of the Neuse "during the late Pleistocene, about 18,000 years ago."

Fishes

Bailey (1977:274) noted that "The Neuse River basin has the richest recorded fish fauna of our watersheds, though it is only third in drainage area." He also pointed out that, except for the white sucker, *Catostomus commersoni* (Lacepède), all of the Tar's fish species also are in the Neuse, but a number of Neuse species may be absent from the Tar. An ictalurid -- *Noturus furiosus* Jordan and Meek, the Carolina madtom -- is endemic to both river systems. Bailey et al. (1977:279) considered this fish a species of Special Concern. Cooper and Braswell (1982) noted: "Based on the very small numbers of specimens taken in recent years, despite intensive sampling at many localities in both rivers, the species seems to have experienced a serious decline." They added, "Its endemicity and apparent rarity make it vunerable to extinction." In October 1984, Braswell and Cooper discovered two populations of *N. furiosus* in the Tar River, one at a site in the Piedmont Plateau and the other at a site in the Coastal Plain. The fish was common at both sites. Thus, *N. furiosus* may be in less trouble in the Tar River basin than it appears to be in the Neuse. The Office of Endangered Species, USFWS, is considering the species for national listing, but not until a pre-listing study has been completed.

Mussels

At least four species of mussels that occur in either or both of the rivers were considered in jeopardy by Fuller (1977). "*Canthyria*" sp., the Tar River Spiny Mussel, is a unique Tar River species about which Fuller said (p. 158), "little is known of its natural history, including the identity of any glochidial host or other aspects of its reproduction." He considered the species to be Endangered in North Carolina. A recent study by Johnson and Clarke (1983) indicated that the former range of this mussel, to which they applied the name *Elliptio (Canthyria) stein-*

stansana, included the Tar River from Nash to Pitt counties. Today it is known from a 12-mile section of the river in Edgecombe County, with a total estimated population of 100 to 500, and is being considered by the U. S. Fish and Wildlife Service for listing as an Endangered species (Federal Register 49(181):36418-36420; 17 September 1984). Close relatives of the Tar River Spiny Mussel occur in the James River basin of Virginia and the Altamaha River basin of Georgia.

The Neuse River population of *Carunculina pulla* (Conrad), the Savannah Shoremussel, may have been extirpated, and declines in its populations elsewhere have been noted. Fuller considered it Endangered in North Carolina. A third mussel considered Endangered by Fuller was *Prolasmidonta heterodon* (Lea), the Ancient Floater. Although known from a number of river systems, including the Neuse and Tar, Fuller noted (p. 169) that it was "one of the most rare, elusive, and vulnerable mollusks in the state and the nation." He also recognized "*Lampsilis" ochracea* (Say), the Tidewater Mucket, as a mussel of Special Concern. One known site of occurrence was the Tar River near Pinetops, Edgecombe County.

Crustaceans

The decapod crustacean fauna of the Neuse and Tar rivers is comparatively rich (both in species and biomass), and probably identical, with both systems housing at least eight crayfish species and a freshwater palaemonid shrimp (listed below). The crayfishes include two endemic species (indicated in the list by asterisk), one of which is an *Orconectes* that appears to be undescribed.

Cambaridae
- *Cambarus (Depressicambarus) latimanus* (LeConte)
- *Cambarus (Depressicambarus) reduncus* Hobbs
- *Cambarus (Lacunicambarus) diogenes diogenes* Girard
- *Cambarus (Puncticambarus) acuminatus* Faxon *(sensu lato)*
- *Fallicambarus (Creaserinus) uhleri* Faxon
- **Orconectes* sp. A (Cooper and Cooper 1977:199)
- *Procambarus (Ortmannicus) acutus acutus* (Girard)
- **Procambarus (Ortmannicus) medialis* Hobbs

Palaemonidae
- *Palaemonetes paludosus* (Gibbes)

Cambarus (D.) reduncus is limited to the Piedmont Plateau. *Cambarus (D.) latimanus, C. (P.) "acuminatus,"* and *C. (L.) d. diogenes* are abundant throughout both rivers, with *diogenes* (an active burrower) the "rarer" of the three. *Orconectes* sp. A appears to occur throughout the Tar River basin, from Granville to Pitt counties, but has not yet

been found west of the Fall Line Zone in the Neuse drainage. *Fallicambarus (C.) uhleri* and *Procambarus (O.) medialis* are Coastal Plain species, but *uhleri* has been found along the eastern edge of the Fall Line Zone in Wake and Franklin counties. Although the type-locality of *medialis* is a roadside ditch on U.S. 258, 0.6 miles (1 km) south of Scotland Neck, Halifax County, the type series and one other lot from near Scotland Neck are the only collections we know of from the Tar river basin; all our collections of this species are from the Neuse River basin. *Procambarus* (*O.*) *a. acutus* is primarily a Coastal Plain species in both systems, but has been found as far west in the Piedmont as the Eno River and its tributaries in Orange County. One other species, *Procambarus* (*Ortmannicus*) *plumimanus* Hobbs and Walton, ostensibly occurs in the lower Neuse River basin. Its type-locality is in the drainage of Slocum Creek, Craven County, which empties directly into the Neuse River Estuary. Nevertheless, none of our Neuse collections contained *plumimanus*, but we have found it relatively common in the White Oak River hydrologic unit.

Other Neuse and Tar crustaceans are now under study, and at least one species of isopod, preyed upon by *N. lewisi*, may be an undescribed endemic.

Miscellany

Centrarchid gamefishes are periodically stocked in the Neuse and Tar rivers. Information on stocking, physicochemical characteristics, fish faunas, general macroinvertebrates, and elevation profiles of these rivers was provided by Bayless and Smith (1962) and Smith and Bayless (1964). Additional physicochemical data, major sources of effluent discharge, biological and chemical pollutants, general macroinvertebrates, and phytoplankton of the Neuse River and its tributaries, collected at 23 stations from the Flat and Eno rivers to the mouth of Broad Creek in the Neuse River Estuary below New Bern, were reported by the Division of Environmental Management, N.C. Department of Natural Resources and Community Development (DNRCD 1980).

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